# NSF EQUIPMENT VERIFICATION TESTING PLAN
# BAG FILTERS AND CARTRIDGE FILTERS

## APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the NSF Equipment Verification Testing Plan for evaluation of water treatment equipment utilizing bag filters or cartridge filters. This Testing Plan is to be used as a guide in the development of the Manufacturer Field Operations Document for testing bag filtration or cartridge filtration equipment, within the structure provided by the NSF Protocol Document, "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants."

In order to participate in the equipment verification process for bag or cartridge filtration, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of the Manufacturer Field Operations Document. The procedures and methods shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific bag filtration or cartridge filtration equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.



Each Manufacturer Field Operations Document shall include Tasks 1 through 6 as described later in this document.

## INTRODUCTION

Water treatment equipment employing bag filtration or cartridge filtration is used in the context of the Surface Water Treatment Rule primarily for removal of *Giardia* cysts and *Cryptosporidium* oocysts.

This Equipment Verification Testing Plan is applicable to the testing of package water treatment equipment utilizing bag filtration equipment or cartridge filtration equipment. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Manufacturer to determine the optimum treatment scheme and most appropriate testing schedule at ~~a~~ the specific geographical location or locations where testing is carried out. The second phase is Verification Testing, which will evaluate performance of the equipment under different raw water quality conditions.

INTERNET DOCUMENT INFORMATION FORM

**A . Report Title**: NSF Equipment Verification Testing Plan Bag Filters and Cartridge Filters

**B. DATE Report Downloaded From the Internet** 2/21 /98

**C. Report's Point of Contact: (Name, Organization, Address, Office Symbol, & Ph #): U. S. Environmental Protection Agency**
Las Vegas, Nevada

**D. Currently Applicable Classification Level**: Unclassified

**E. Distribution Statement A**: Approved for Public Release

**F. The foregoing information was compiled and provided by:**
**DTIC-OCA, Initials:** VM **Preparation Date:** 2/21/98

The foregoing information should exactly correspond to the Title, Report Number, and the Date on the accompanying report document. If there are mismatches, or other questions, contact the above OCA Representative for resolution.

Verification Testing will be done during ~~the winter, spring, summer, and fall seasons, or during other~~ time periods when the source water or feed water quality is appropriate for testing the full range of water quality conditions that ~~could be experienced within a regional geographical area~~ need to be evaluated. Development and execution of well-documented testing covering a wide range of water quality has a better chance of minimizing subsequent on-site testing which states may require before approving use of the equipment at specific locations.

## GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with an NSF-qualified analytical laboratory.

## OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the bag filtration and cartridge filtration Verification Testing program. Tasks A and B are sequential tasks done before Verification Testing. Tasks 1 through 6 are to be done during Verification Testing and have overlapping time frames.

**Task A: Characterization of Feed Water.** The objective of this ~~recommended~~ Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

**Task B: Initial Tests Runs.** During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task.

**Task 1: Verification Testing Runs.** Water treatment equipment shall be operated for a minimum of 30-days ~~period~~ during each of four ~~seasons~~ testing periods to collect data on equipment performance and water quality for purposes of performance verification.

**Task 2: Feed Water and Finished Water Quality.** During each day of Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken. If pre-filtration clarification equipment is used, its effect on water quality shall be documented.

**Task 3: Operating Conditions and Treatment Equipment Performance.** During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented including filtration rate and rate of filter head loss gain. If pre-filtration equipment is used, the equipment shall be described, and the operating conditions shall be documented.

**Task 4: Microbiological Contaminant Removal.** The objective of this task is to evaluate removal of microbiological contaminants or surrogates during Verification Testing by measuring removal of *Giardia* cysts or *Cryptosporidium* oocysts or of protozoan-sized particles seeded in the feed water, or by undertaking a combination of the above techniques.

**Task 5: Data Management.** The objectives of this task are to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and the NSF for data obtained during the Verification Testing and to develop statistical analysis of certain test data.

**Task 6: QA/QC.** An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during bag filtration or cartridge filtration equipment Verification Testing.

## TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over four 30-day periods, not including mobilization, start-up, and Initial Operations.

A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

## DEFINITIONS

Definitions that apply for bag filtration and cartridge filtration processes include:

**Bag Filter**: A non-rigid, disposable, fabric filter in which flow generally is from the inside of bag to the outside. One or more filter bags are contained within a pressure vessel designed to facilitate rapid change of the filter bags when the filtration capacity has been used up. Bag filters generally do not employ any chemical coagulation, if pretreatment is employed. <u>For these filters, pretreatment is likely to consist of prefiltration or prechlorination.</u> The pore sizes in the filter bags <u>designed for protozoa removal</u> generally

are small enough to remove protozoan cysts and oocysts but large enough that bacteria, viruses and fine colloidal clays would pass through.

**Cartridge Filter**: A rigid or semi-rigid, disposable, self-supporting filter element in which flow generally is from the outside of the cartridge to the inside. One or more filter cartridges are contained within a pressure vessel designed to facilitate rapid change of the cartridges when the filtration capacity has been used up. Cartridge filters generally do not employ any chemical coagulation, if pretreatment is employed. <u>For these filters, pretreatment is likely to consist of prefiltration or prechlorination.</u> The pore sizes in the filter cartridges <u>designed for protozoa removal</u> generally are small enough to remove protozoan cysts and oocysts but large enough that viruses and fine, sub-micron colloidal clays would pass through.

**Filtration:** A process for removing particulate matter from water by passage through porous media.

<u>**Prechlorination:** Chlorination done at the beginning of treatment. Some regulatory agencies may require prechlorination to retard microbial growth on the bag or cartridge filters.</u>

**Prefiltration**: A first-stage filtration process sometimes used ahead of bag filters or cartridge filters. Prefilters generally do not employ chemical pretreatment, but are instead intended to remove coarser particulate matter, thus prolonging the life of the bag filter or cartridge filter being used to remove protozoan cysts or oocysts.

## TASK A: CHARACTERIZATION OF FEED WATER

### Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the bag filtration or cartridge filtration equipment to be tested. This task should be undertaken with great care, because of the limited capability of bag filters and cartridge filters to remove fine colloidal clays that cause turbidity in many surface waters and because feed waters having high concentrations of particulate matter such as algae, ~~biological particles~~ <u>consisting of plant material</u>, or sediment can rapidly clog bag filters and cartridge filters, necessitating replacement of the clogged filters.

If the source water used as feed water for the testing program has an excessive amount of the fine turbidity-causing particles, the bag filtration or cartridge filtration equipment may not be able to attain sufficient turbidity removal to meet the requirements of the Surface Water Treatment Rule. Because bag filters and cartridge filters do not remove viruses, the entire burden of virus control falls on the disinfection process when these filters are used for water treatment. Excessive turbidity in filtered water could present problems in attaining effective disinfection and would be a likely cause for rejection of bag filters or cartridge filters by drinking water regulators.

If the source water used as feed water consistently has a very low turbidity and very low concentration of algae and other particulate matter, drinking water regulators may be reluctant to approve cartridge filters or bag filters for applications in which the source water turbidity or particulate matter concentration is higher (Alaska Department of Environmental Conservation, 1994). The feedwater quality chosen for Verification Testing can influence both performance of the filtration equipment and the potential for acceptance of testing results by state regulatory agencies.

**Objectives**

The objective of this task is to obtain ~~a complete~~ data from one or more years for the chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested. Factors of particular interest include conditions that affect bag filter and cartridge filter cycle lengths, such as turbidity in runoff events following heavy rainfall or snowmelt, or algae blooms.

**Work Plan**

This task can be accomplished by ~~using analytical measurements~~ compiling data obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Turbidity, Algae, Temperature, and pH
- Total Coliform, Total Alkalinity, Hardness, and True Color
- Total Suspended Solids

Sufficient information shall be obtained to illustrate the timing and degree of variations expected to occur in these parameters that will be measured during Verification Testing for a typical annual cycle for the water source, if all testing is done at a single site. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the

testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) or animal activities with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

### Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a bag filtration and cartridge filtration Verification Testing program.

### Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance capabilities and the Surface Water Treatment Rule. If the turbidity of the feed water is substantially greater than 1 nephelometric turbidity unit (ntu) and periodically exceeds 5 ntu, producing filtered water with an acceptable turbidity may be difficult. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment by the equipment in question.

## TASK B: INITIAL TEST RUNS.

### Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task and may occur during each of the periods in which Verification Testing is to be done. Initial test runs are required before the start of the first period of Verification Testing so an NSF field audit of equipment operations and sampling and field analysis procedures ~~will~~ can be carried out during the initial test runs.

**Objectives**

The objective of these test runs is to determine the proper approach for treatment of the feedwater during Verification Testing. Treatment requirements may be different for feedwaters from different test sites or for the feedwater from the same site ~~during different seasons~~ at different times of testing. Therefore, conducting initial test runs for each testing period is strongly recommended. Some source waters used as feedwater may require prefiltration to remove coarse particulate matter, as a means of extending the life of the bag filters or cartridge filters that will be used for the control of microorganisms. Testing may also be needed to demonstrate the level of filtered water turbidity that the equipment can produce at the test site.

**Work Plan**

~~Exploratory~~ Initial tests for bag filtration and cartridge filtration can be conducted using the filtration equipment that would be used for Verification Testing, so an assessment could be made to determine whether prefiltration might be needed during verification testing. During exploratory tests, filters can be operated until terminal headloss is reached or until sufficient data are collected to facilitate making reliable projections on the total volume of water that could be filtered through a filter bag or cartridge before it clogs and must be replaced.

**Analytical Schedule**

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, the NSF will be conducting an initial on-site audit of field operations, sampling activities, and on-site sample analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site audit.

**Evaluation Criteria**

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance capabilities with regard to water quality. If the performance was not as good as the statement of performance capabilities, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program. In addition, the initial test run results on expected water production per

individual filter bag or filter cartridge may provide guidance regarding the need for prefiltration ahead of the bag filtration or cartridge filtration equipment to be operated during Verification Testing.

## TASK 1. VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

### Introduction

Package plant water treatment equipment employing bag filtration or cartridge filtration shall be operated for Verification Testing purposes, with the approach to treatment based on the results of the Initial Operations testing.

### Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer ~~and to assess its ability to meet the water quality goals and any other performance characteristics specified by the Manufacturer in the statement of performance capabilities~~ <u>for periods of 30 days or longer and to evaluate equipment performance under a range of circumstances including installation of new bags or cartridges and attainment of terminal head loss.</u>

### Work Plan

<u>Verification Testing Runs</u>

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. To obtain a ~~seasonal~~ perspective on the overall performance of the equipment, four Verification Testing periods, each lasting for a minimum of 30 days, are anticipated for evaluating the performance of a treatment system. ~~One~~ Verification Testing ~~period~~ shall be conducted ~~during each season~~ <u>under conditions likely to provide a wide range of feed water quality for testing purposes</u>. During each ~~of these~~ testing period, Tasks 1 through ~~5~~ <u>6</u> shall be conducted simultaneously.

~~Seasonal operation~~ <u>Testing over a wide range of feed water quality</u> is required because of the differences in water quality that occur on a seasonal basis. For bag filtration and cartridge filtration treatment equipment, factors that can influence treatment performance include:

- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis in spring, summer or fall
- lake or reservoir turnover, if this results in bottom sediments being suspended and carried up closer to the surface where they enter the source water (feedwater) intake

It is highly unlikely that all of the above problems would occur in a surface water during a single ~~season~~ testing period, and this results in the requirement for multiple testing periods or multiple sites or both to capture critical events that affect water quality. ~~during each season of the year~~.

Routine Equipment Operation

If the package water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the SDWA primacy agency shall also be supplied to the NSF-qualified Testing Organization.

**Schedule**

During Verification Testing, water treatment equipment shall be operated for a minimum of 30 days. Bag filtration or cartridge filtration package treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss is attained. When terminal head loss is attained, the clogged bag or cartridge shall be removed and replaced with a new one, and operation shall resume. Filter runs shall not be stopped before turbidity breakthrough or terminal head loss except because of equipment failure or power interruption or for purposes of conducting seeded microsphere challenge tests, because data on complete filter runs are needed to fulfill the objectives of Verification Testing. During Verification Testing, the equipment shall be operated in a stop-start mode in conjunction with challenge tests described in Task 4. The duration of each filter run and the number of gallons of water produced per square foot (or cubic meters of water produced per square meter) of filter area or the volume of water produced by a specified bag or cartridge shall be recorded in the operational results.

During routine equipment operation, the package water treatment equipment should be operated in a manner appropriate for the needs of the water system.

**Evaluation Criteria**

The goal of this task is to operate the equipment for the 30-day period, including time for changing prefilters or bag or cartridge filters and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 30 days or more.

If routine equipment operation is also conducted, the data supplied to the NSF-qualified Testing Organization shall be evaluated with regard to SDWA compliance.

## TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY.

### Introduction

Surface waters of high quality are the only surface waters appropriate for treatment by bag filtration and cartridge filtration equipment. Characterization of the feed water is very important, as feed water quality can strongly influence the performance of this equipment. Bag filters and cartridge filters function by straining, so a mat or cake builds up on the filter surface and in the pores of the filter medium. If the materials being removed are not compressible, such as hard, mineral materials, the build-up of this cake may not hinder filtration seriously. On the other hand, removal of compressible particles such as algae or fragments of biological matter can cause the filter to become blinded. Because filtration of some types of particles can blind bag and cartridge filters, they are appropriate only for high quality waters. Turbidity of a source water may not be an adequate indicator of its suitability for treatment by these filters. The volume of water that can be filtered could vary by a factor of ten fold or greater for water of a given turbidity, depending on the nature of the particulate matter in the raw water because turbidity can not indicate whether particles are compressible or incompressible.

As always in Verification Testing, characterization of the filtered water is very important. Water quality data shall be collected for the feedwater and filtered water as shown in Table 2, during ~~each day of~~ Verification Testing. At a minimum, the required sampling schedule shown in Table 2 shall be observed by the Testing Organization on behalf of the Manufacturer. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Manufacturer Field Operations Document in the statement of capabilities.

### Experimental Objectives

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 2. The actual water quality parameters selected for testing shall be stipulated by the

Manufacturer in the Manufacturer Field Operations Document and shall include all those necessary to permit verification of the statement of performance capabilities. If the water being filtered tends to cause rapid increases in head loss, efforts should be made to identify the nature of the particulate matter that is causing the rapid clogging. If prefiltration is used, the performance of the prefilter or prefilters with respect to water quality ~~should~~ must also be documented. Without such documentation the range of water quality for which bag filtration or cartridge filtration equipment may be accepted could be considerably more restricted.

The characterization of feed water is intended to provide sufficient information to enable State drinking water regulators to compare the quality of the feed water used in Verification Testing with the quality of source water at a site where the use of the equipment may be proposed.

**Work Plan**

The manufacturer will be responsible for establishing the filtration equipment operating parameters, on the basis of the initial ~~Operations testing~~ test runs. The bag filtration or cartridge filtration equipment shall be operated continuously until terminal headloss is attained, unless operation is stopped and restarted for a microsphere challenge test. If terminal head loss is reached, the filter bag (or bags) or filter cartridge (or cartridges) shall be replaced with new ones, and filtration operations shall be resumed and continued until the end of the 30-day period.

Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified Testing Organization ~~(refer to Table 3)~~. Analysis of the remaining water quality parameters will be performed by an NSF-qualified analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods section below and in Table 3. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures. One analytical procedure that is not required but which might prove helpful if excessive clogging of the filters is encountered is the Microscopic Particulate
Analysis (MPA) for Filtration Plant Optimization ~~(*Standard Methods*, 1995)~~ (EPA 910-R-96-001.)

Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined by the Manufacturer in the Manufacturer Field Operations Document.

In the case of water quality samples that will be shipped to the NSF-qualified, analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the NSF-qualified, analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

**Analytical Schedule**

During Verification Testing for bag filtration and cartridge filtration treatment equipment, the feedwater (raw water) quality and filtered water quality shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (daily)
- total alkalinity (weekly)
- hardness (weekly)
- total organic carbon (weekly)
- iron (once per test period if less than 0.3 mg/L, or weekly if above 0.3 mg/L in feed water)
- manganese (once per test period if less than 0.05 mg/L, or weekly if above 0.05 mg/L in feed water)
- algae, number and species (weekly if no pre-filtration used, three times per week if the pressure drop [head loss] across the bag filter or cartridge filter increases by more than 5 percent of the total head loss initially available in one day's time per day)
- $UV_{254}$ absorbance (weekly)
- true color (weekly)
- total coliform bacteria (twice per week)
- turbidity (continuous for filtered water)
- particle counts (see Task 4)

If prefiltration is done to condition the feed water for treatment by bag filtration or by cartridge filtration, the water discharged from the prefiltration process shall be sampled and the following water quality parameters shall be measured:

- iron (~~weekly~~ same as above )
- manganese (~~weekly~~ same as above)
- algae, number and species (three times per week)
- turbidity (continuous)
- particle counts (see Task 4)
- TOC, true color, and $UV_{254}$ absorbance

Turbidity of filtered water shall be measured and recorded using a continuous, flow-through turbidimeter. Turbidity of feed water (before seeding of microorganisms or microspheres) shall be measured continuously using a flow-through turbidimeter or at intervals of not more than four (4) hours if a bench model turbidimeter is used for grab samples. On a daily basis a bench model turbidimeter shall be used to check the continuous turbidimeter readings.

The above water quality parameters are listed to provide State drinking water regulatory agencies with background data on the quality of the feed water being treated and data on the quality of the filtered water. These data are to be collected to enhance the acceptability of the Verification Testing data to a wide range of drinking water regulatory agencies.

**Evaluation Criteria**

Evaluation of water quality in this task is related to meeting the requirements of the Surface Water Treatment Rule, plus any general water quality capabilities indicated by the Manufacturer.

- Turbidity removal equals or exceeds requirements of Surface Water Treatment Rule
- Water quality and removal goals specified by the Manufacturer
- Water quality improvement attained by prefiltration

Where applicable, the regulations proposed in the Enhanced Surface Water Treatment Rule (ESWTR) shall also provide guidance for the treatment goals established in the Manufacturer's statement of performance capabilities and shall be considered in the evaluation criteria.

## TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE.

**Introduction**

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain, water pressure at the inlet to the bag filter or cartridge filter pressure vessel, length of filter run and terminal head loss. Operating conditions are likely to be evaluated in great detail by state reviewers and are an important aspect related to approval of equipment.

**Objectives**

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

**Work Plan**

A complete description of each process shall be given. Data on the filter shall be provided and shall include the following:

- flow capacity
- nominal pore rating of filter bag or filter cartridge and the method used to determine this pore rating
- number of filter bags or filter cartridges housed within the pressure vessel
- maximum operating pressure of filter vessel
- volume of filter vessel
- if any pre-filtration equipment is used, a complete description of the pre-filtration equipment shall be provided that conveys the same types of the information required for bag filtration or cartridge filtration equipment.

In addition, system reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated. Some of the above requirements might be met by providing manufacturer's engineering drawings of the equipment used in Verification Testing.

During each day of Verification Testing, treatment equipment operating parameters for bag filtration and cartridge filtration will be monitored and recorded on a routine basis. This shall include rate of flow, filtration rate, pressure at filter vessel inlet and outlet, and maximum head loss. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption

during operation. Performance shall be evaluated to develop data on the number of gallons of water that are treated by each bag or cartridge and on energy needed for operation of the process train being tested.

A daily log shall be kept in which events in the watershed are noted if they could influence source water quality. This includes such things as major storm systems, rainfall, snowmelt, temperature, cloud cover, upstream construction activities that disturb soil, and intermittent operation of hydroelectric generating facilities.

If prefiltration equipment is used, the performance of that equipment shall be documented in the same manner as the bag filtration or cartridge filtration is documented.

Performance of bag filtration and cartridge filtration for removal of turbidity and microorganisms can be strongly influenced by the pore sizes of the bag filter or the cartridge filter. Therefore the manufacturer's specifications on the bag filter or cartridge filter used when turbidity or microorganism data are gathered shall be identified. ~~If bag filters or cartridge filters having different pore size specifications are used during Verification Testing, the water quality data collected in conjunction with the use of each bag filter or cartridge filter of a specified pore size shall be analyzed and presented separately.~~

### Schedule

Table 4 presents the schedule for observing and recording bag filtration and cartridge filtration package plant operating and performance data.

### Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance capabilities. The quantity of water that is produced and meets quality criteria for acceptance will be an important factor in this evaluation.

If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

## TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL

### Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of bag filtration and cartridge filtration treatment processes for microbial removal will be evaluated in this task. Assessment of treatment efficacy will be made on the basis of particle counting and removal of polymeric microspheres. Testing for removal of protozoan microorganisms is optional.

The bag filtration and cartridge filtration process removes particles, including microorganisms, in the size range of *Giardia* and *Cryptosporidium* from water by physically straining out the particles and trapping them in the bag filter or cartridge filter. Because particle removal is accomplished primarily by straining out particles from water on the basis of the sizes of the particles and of the pores in the filter, the applicability of surrogate particles depends on their size, ~~and~~ shape and pliability, rather than on their biological nature. Thus appropriately sized microspheres could be suitable surrogates for protozoan cysts and oocysts. Bag filtration and cartridge filtration equipment now is produced for purposes of removing the smaller *Cryptosporidium* oocysts, so testing for *Giardia* cyst removal is not needed.

Cysts and oocysts are biological particles without hard shells or skeletons, so they are capable of deforming somewhat and squeezing through pores that might seem to be small enough to prevent their passage. In addition, the pore sizes for filter bags and filter cartridges is not absolute, and these filters will have some pores that are both larger and some that are smaller than the nominal size. Therefore they do not provide an absolute cutoff for particles at or slightly larger than their nominal size. For these reasons, microspheres used in challenge tests should be close to or slightly smaller than the smallest size for the protozoan organism for which the microspheres are a surrogate.

Removal of turbidity by bag filtration and cartridge filtration is not synonymous with removal of protozoan organisms because turbidity-causing particles can be much smaller than protozoa. This results in bag filters and cartridge filters being able to remove protozoan-sized particles while passing particles in the size range of bacteria, or the micron-sized and sub-micron-sized particles that cause turbidity. Therefore turbidity removal is not a surrogate for protozoan removal in bag filtration and cartridge filtration.

Use of electronic particle counting to assess protozoan removal would be appropriate only for feed waters containing large numbers of particles in the size range of *Cryptosporidium*. ~~the protozoan of concern. For *Giardia* cyst removal, assessment of particle removal for particles in the size range of 6 μm and greater (to allow for clumped *Giardia*) would be appropriate.~~ ~~For~~ *Cryptosporidium* oocyst removal, assessment of particle removal in the size range of ~~3~~ 2 to 6 μm ~~and greater~~ would be appropriate because *Cryptosporidium*, which can be as small as 3 μm, can deform under pressure and may squeeze through pores that are smaller than the smallest dimension of the oocyst. If sufficient concentrations of

appropriately sized particles are not present in the feed water, use of electronic particle counting may not be capable of demonstrating adequately high log removals.

**Experimental Objectives**

The objective of this task is to evaluate removal of particles and microbiological contaminants during Verification Testing by measuring removal of microorganisms seeded into the feed water or by assessing removal of polystyrene fluorescent microspheres if *Cryptosporidium* oocysts are not seeded into the feed water, and by electronic particle counting ~~or with a combination of these techniques.~~ ~~Seeded microorganisms may be *Giardia* cysts or *Cryptosporidium* oocysts. *Giardia* cysts are larger than *Cryptosporidium* oocysts, so removal of *Giardia* cysts to a particular degree of efficacy does not ensure removal of *Cryptosporidium* oocysts to that same degree. Manufacturers of equipment intended to remove *Cryptosporidium* oocysts should arrange for testing of *Cryptosporidium* or for testing involving *Cryptosporidium*-sized surrogates.~~

**Work Plan**

~~The portions of Task 4 (required portions plus optional portions, if any shall be carried out during the Verification Testing runs being conducted in Task 1. Testing may be done with *Giardia* cysts or *Cryptosporidium* oocysts or with surrogates.~~
Task 4 shall consist of particle counting and tests involving seeded *Cryptosporidium* oocysts or seeded microspheres, or of both seeded oocysts and seeded microspheres if the manufacturer chooses to test both.

Seeding Technique

The purpose of this task is evaluation of the bag filter or cartridge filter for microorganism removal, so any seeding of ~~protozoan organisms~~ *Cryptosporidium* or ~~surrogates~~ microspheres shall be done after the feed water has passed prefiltration equipment and just prior to the entry of the water into the bag filtration or cartridge filtration equipment, unless the prefilter and the bag or cartridge filter are designed and sold as a single package plant having filters in series. During seeding tests, the concentrated suspension of microspheres or oocysts shall be gently stirred to maintain the particles in suspension. The concentrated microspheres shall be suspended in a solution of distilled or deionized water with 0.01% Tween 20. Before each run with seeded microspheres, the holding vessel shall be washed with hot water and laboratory glassware detergent and thoroughly rinsed with tap water or filtered water. The oocyst suspension shall be kept chilled during seeding. Microspheres or oocysts shall be added to the feed water using a variable speed chemical feed pump. Mixing of seeded particles into the feed water shall be done with an in-line mixer that attains a head loss of about 0.3 to 0.5 feet of water during operation.

Electronic Particle Counting

When an electronic particle counter is used for evaluation of particle removal, particle counts in feed water just before entry into the bag filtration or cartridge filtration equipment shall be measured to determine the concentration of particles before filtration, and particle counts in the filtered water shall be measured. ~~When particle counting is used as a surrogate for assessing *Giardia* cyst removal, particles in the size range of 6 µm and greater (to allow for clumped *Giardia*) shall be counted.~~ For assessing *Cryptosporidium* oocyst removal and removal of larger organisms, particles in the size range of ~~3~~ 2 µm ~~and greater~~ to 6 µm shall be counted. If appropriately sized particles are not present in sufficient densities (concentrations) in the feed water to permit calculation of log removals consistent with the Manufacturer's statement of performance capability, then particle counting for log removal should be done during microsphere challenge events.

~~Fluorescent~~ Microspheres

Evaluation of microsphere removal shall be conducted by measuring the density (or concentration) of microspheres seeded on a continuous basis in the feed water and then measuring the density (or concentration) of microspheres in the filtered water or by determining the number of microspheres added to the feed water in a slug dose and then measuring the total number of microspheres detected in the filtered water. The nominal diameter shall be ~~3~~ 2 µm, because *Cryptosporidium* oocysts are considerably smaller than *Giardia* cysts, and a bag filter or cartridge filter capable of attaining a certain degree of removal for *Cryptosporidium* will attain an equal or greater removal of *Giardia*, based on the filtration mechanism being straining or physical blockage of the passage of particles through the filter when all operating conditions are the same.

~~If microspheres are intended to serve as surrogates for *Giardia* cysts only, the nominal diameter of the microspheres used shall be 5µm or 6µm. If the microspheres are intended to serve as surrogates for both *Giardia* cysts and *Cryptosporidium* oocysts;~~

The number of microspheres used shall be sufficient to permit calculation of log removals that exceed the removal capability as set forth in the Manufacturer's statement of performance capabilities. Recovery of microspheres in filtered water provides data for use in calculating definite removal percentages, in contrast to the practice of reporting removals that exceed a specified value based on the detection limit, which would have to be done when no microspheres are detected in filtered water. For testing involving microscopic enumeration, fluorescent microspheres ~~shall be used,~~ and an optical microscope equipped with ultraviolet illumination shall be used. ~~to enumerate the microspheres~~.

If microspheres are seeded into the feed water on a continuous basis, determination of microsphere density by means of electronic particle counting may be feasible, depending on the statement of performance related to the log removal that can be attained by the filtration equipment and depending on the density (concentration) of microspheres that can be seeded into the feed water. If electronic particle counting is not feasible, enumeration of microspheres in feed water and filtered water by optical microscopy shall be required.

Two techniques for analysis of water samples containing fluorescent microspheres may be used. One is the method used by Abbaszadegan et al. (1997) for enumeration of *Giardia* cysts and *Cryptosporidium* oocysts, and the other is the method of Li et al. (1997) which they used for enumeration of microspheres.

If the techniques for microsphere sampling and enumeration ~~shall be~~ are based on the research work of Li *et al.* (1997) which was carried out at the U.S. EPA's research laboratory in Cincinnati, the procedures below shall be followed.

Samples of feed water seeded with microspheres and samples of filtered water shall be filtered through 1 $\mu$m pore size, 293 mm diameter polycarbonate membranes. A stainless steel filter manifold shall be used to support the polycarbonate membrane. Volume of water filtered, and the times of initiation and completion of filtration shall be noted. The filter shall be removed from the manifold and placed in a container specified by the Analytical Laboratory, and refrigerated until shipped to the NSF-qualified Analytical Laboratory. At the analytical laboratory the microspheres removed from the filter with a laboratory squeegee and by washing with about 200 mL of 0.01% Tween 20. The liquid and particulate matter removed from the membrane shall be concentrated to a volume of between 1 and 10 mL by means of centrifugation for 10 minutes at 1200 x gravity. The volume of the concentrated suspension shall be recorded. Microspheres shall be enumerated using a hemacytometer under a UV microscope at 400 magnification. A minimum of three hemacytometer counts shall be performed for each sample. The volume of suspension examined in the hemacytometer shall be recorded and used to determine the fraction of the original water sample which was ultimately examined under the microscope.

*Standard Methods* states that hemacytometer chambers come with detailed manufacturer's instructions concerning calculations and proper usage. *Standard Methods* contains the precaution that disadvantage of hemacytometers is that the sample must have a very high density of objects being counted in order to yield statistically reliable data. Some exploratory tests may be needed to identify appropriate volumes of treated water to filter through the polycarbonate membrane or appropriate densities (concentrations) of microspheres in the seeded feed water, so that reliable statistics can be attained in filtered

water analysis. The total number of microspheres counted in the hemacytometer should be between 30 and 300 to obtain good statistical results without counting overwhelming numbers of microspheres.

If the entire flow stream produced by the bag filtration or cartridge filtration equipment can not be filtered through the 293 mm membrane filter for sampling, a measured portion of the total filtered water flow can be sampled as it is produced, or the entire flow of filtered water from a seeding test can be stored in clean vessel and later filtered through the 293 mm membrane filter at a rate of flow suitable for the membrane filter. If an instantaneous slug dose of microspheres is applied and the entire volume of filtered water is saved in a storage vessel for subsequent membrane filtration as the sampling procedure, a volume of filtered water of at least 20 times the volume of the bag filter or cartridge filter pressure vessel shall be filtered through the bag or cartridge filtration equipment and saved for sampling and analysis.

<u>Organisms Employed for Challenge Tests</u>

Microbiological testing, if done, shall be performed by seeding ~~*Giardia* cysts or~~ *Cryptosporidium* oocysts ~~or both~~ into the feed water and by analyzing for the organism~~s~~ in question in the feed water and in the filtered water.

~~If testing is done with seeded organisms,~~ The ~~microorganisms~~ <u>oocysts</u> shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension.) The reservoir will be mixed continuously throughout the experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer.

<u>The analytical methods used for *Cryptosporidium* oocysts lack precision. The method required to be used for the Information Collection Rule (ICR) should be followed at the present time. When improvements to the *Cryptosporidium* method are tested, peer reviewed, evaluated by several laboratories, and then accepted by the U.S. EPA or are published by *Standard Methods*, the improved methods should be followed.</u>

**Analytical Schedule**

<u>Particle Counting</u>

Analysis of feed water samples by electronic particle counters may be measured on a batch or a continuous basis. If batch measurements are made, they shall be made for at least 8 hours each working day during Verification Testing, with samples collected and analyzed at least once each hour. Filtered water analysis shall be done using flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

On days when microsphere challenge tests or microbiological challenge tests are undertaken, particle counting activities shall be coordinated with the challenge test sampling activities so particle count data are available ~~on both particle counts and~~ for every sample that is analyzed for microspheres or microorganisms. ~~for the same water samples.~~ On days when challenge tests are not carried out, at least ~~four~~ eight feed water samples shall be obtained for particle counting and for purposes of comparison with filtered water so calculation of log removal of particles can be done.

Microsphere Samples

Planning a sampling schedule for bag filtration or cartridge filtration equipment may be challenging, as the length of a filter run could exceed the 30 days allotted for intense sampling and analysis called for in Verification Testing runs. If the Initial Test Runs conducted during Task B indicate that evaluating three filter runs during the 30 days of Verification Testing will not be possible because of the long duration of the runs, then three sets of microsphere samples shall be collected at each time when seeding is done during the filter run. This will provide data that can be used for statistical analysis, during each ~~season~~ time period when Verification Testing is done.

During each microsphere challenge test run, microspheres shall be seeded for evaluating the performance of a continuously running filter three times during a run: at the start-up of the equipment, after a new filter bag or filter cartridge has been installed, near the middle of the run when head loss has approached one half of the recommended terminal head loss, and near the end of the run after head loss has exceeded 90 percent of recommended terminal head loss. In addition, after the seeding challenge and sampling event in the middle of the run has been completed, the filter flow shall be stopped and preparations shall be made for another round of sampling. The filter shall be restarted and sampling shall be done again, to evaluate the effect of stopping and starting a filter that has removed a very large number of microspheres.

The timing for collection of samples shall be different based on whether continuous seeding or slug dose seeding is used. When microspheres are seeded on a continuous basis, microsphere samples shall be collected from the plant influent (feed water after seeding) and the filter effluent. Samples shall not be collected until the treatment plant has

been in operation for a total of 3 theoretical detention times as measured through the filter vessel. For microsphere sampling purposes, the time of operation when 3 filtration vessel detention times have elapsed shall be considered time zero. Four microsphere samples shall be collected, beginning at time zero and at 0.5, 1.0 and 2.0 hours. The exact time of sampling will be recorded so turbidity measurements can be determined at the time of sampling. Volumes of feed water and filtered water to be filtered should be large enough that 30 to 300 microspheres are detected in each seeded feed water sample. Ideally for statistical purposes 30 to 300 microspheres should be detected in each filtered water sample also. If the filtration process is highly efficient for removal of the microspheres, detection of such large numbers in samples of filtered water would not be possible. In such a case, detection of at least 5 microspheres is desirable. If removal is extremely high, detecting 5 or more microspheres in filtered water may not be possible but probably would be indicative of very high log removals of microspheres.

When microspheres are seeded on a slug dose basis, slug doses shall be seeded at the beginning of operation, just after flow is turned on in a filter, and after the filter has operated long enough to attain 85 to 95 percent of the total available head loss. When the filtration equipment is operating at high head loss (having attained 85 to 95 percent of total available head loss) after a slug dose has been applied and the required volume of water has been filtered, the flow shall be turned off and then restarted, and a second filtered water sample shall be collected to assess the effects of intermittent operation.

For seeding on a slug dose basis, The number of microspheres in the concentrated suspension shall be based on an analysis of the concentrated suspension before it was dosed. The entire production of filtered water shall be collected for sampling, from the instant of dosing until a volume of filtered water equal to 20 volumes of the filter vessel have been collected. For example, if the filter vessel volume is 40 liters, an 800 liter sample of filtered water shall be collected and then filtered through a membrane filter as described above in the procedure of Li *et al.*
Microsphere samples shall be analyzed by an NSF-qualified analytical laboratory.

After the first ~~season's~~ round of Verification Testing has been done, the results of equipment performance shall be reviewed. If terminal head loss was not approached in the bag filtration or cartridge filtration equipment, it may be desirable to operate the filtration equipment until the filters are approaching terminal head loss and then start another period of Verification Testing with nearly-clogged filters, so challenge testing can be undertaken to evaluate that aspect of filter performance. Failure to do this could cause a serious gap in filter performance data and could have an impact on acceptability of the equipment by state regulators.

Microbiological Samples

Microbiological samples shall be collected from feed water and filtered water on the same schedule stipulated for microsphere samples.

The Testing Organization shall then submit collected water samples to an NSF-qualified analytical laboratory for microbial testing.

**Evaluation Criteria**

Performance evaluation shall be conducted in a number of ways, depending on the types of data collected during testing.

Performance of bag filtration and cartridge filtration package plants shall be evaluated in the context of the Manufacturer's statement of performance capabilities and the filtered water turbidity requirements of the SWTR. Turbidity results will be analyzed to determine the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, the percentage between 1.0 and 5 NTU, and the percentage that exceeded 5 NTU. The time intervals used for determining filtered water turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be ~~between 15 and 60 minutes~~ 1/4, 1/2, or 1 hour. In addition, the highest filtered water turbidity observed each day shall be tabulated.

Electronic particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. Because of possible complications in conducting electronic particle counts on feed water, 1 to 4 hour time intervals shall be used for analysis of particle counting data for log reduction of particles. In addition, particle count data for filtered water shall be presented as time series data showing trends of particle counts with passage of time. Data shall be presented showing particle counts in filtered water at time intervals no longer than one hour for the 30 days of Verification Testing.

Data on the density (concentration) of microspheres or protozoa in feed water and filtered water shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. This analysis shall be done separately for each filter operating condition: at start-up with a new bag or cartridge, mid-way through a run, and after ~~90~~ 85 to 95 percent of terminal head loss has been attained.

**TASK 5: DATA MANAGEMENT.**

## Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software or manual recording methods, or both, for recording operational parameters for the bag filtration or cartridge filtration equipment on a daily basis.

## Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for the NSF for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants."

## Work Plan

### Data Management

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the bag filtration and cartridge filtration equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to NSF-qualified analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

If filter bags or cartridges having different design specifications are used during Verification Testing, each filter bag or cartridge shall be operated for a minimum of 30 days, and the water quality data collected in conjunction with the use of each type of bag or cartridge shall be analyzed and presented separately.

Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants."

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Each of the four conditions described in Task 4 (start of run, middle of run before flow stops, middle of run after flow is stopped and restarted, and near end of run approaching terminal head loss) shall be analyzed separately for 95% confidence intervals. Information on the differences in water quality for the beginning, the middle, and the end of filter runs would be useful in evaluating the effect of installing a new bag or cartridge, and the effect of approaching terminal head loss. Data on microsphere removal in the middle of the run, before and after

the filter flow was stopped, can be used to assess the effects of stopping and starting the flow in bag filtration or cartridge filtration equipment.

**TASK 6: QA/QC.**

**Introduction**

Quality assurance and quality control of the operation of the bag filtration and cartridge filtration equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

**Experimental Objectives**

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

**Work Plan**

Equipment flow rates and associated signals should be verified and verification recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters, etc. will be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

<u>Daily QA/QC Verifications:</u>

- In-line turbidimeter flow rates (verified volumetrically over a specific time period)
- <u>In-line turbidimeter readings checked against a properly calibrated bench model</u>
- Batch and in-line particle counter flow rates (verified volumetrically over a specific time period).

<u>Bi-weekly QA/QC Verifications:</u>

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

~~Seasonal~~ QA/QC Verifications at Start of Each Testing Period:

- In-line turbidimeters (clean out reservoirs and recalibrate)

- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)

- Tubing (verify good condition of all tubing and connections, replace if necessary)

- Particle counters (perform microsphere calibration verification)

**On-Site Analytical Methods**

The analytical methods utilized in this study for on-site monitoring of raw water and ~~permeate~~ filtered water quality are described in the section below. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

pH

Analysis for pH shall be performed according to *Standard Methods* 4500-$H^+$. A 2 point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended.

Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1 °C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

Color

True color shall be measured with a spectrophotometer at 455 nm, using a Hach Company adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples can not be analyzed immediately they shall be stored at 4°C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 with either a bench-top or in-line turbidimeter. Grab samples shall be analyzed using a bench-top turbidimeter; readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

*Bench-top Turbidimeters*

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

*In-line Turbidimeters*

In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to ~~periodically~~ verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

Particle Counting

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

A bench-top particle counter may be used to analyze the raw and pretreated waters (where applicable). Continuous flow particle counters shall be employed for monitoring of particles in the finished waters.

*Bench-top Particle Counters*

All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 $\mu$m. There should be less than a ten percent coincidence error for any one measurement.

*Calibration.* Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated mono-sized polymer microspheres. This calibration should be verified ~~on a quarterly basis during pilot testing~~ at the beginning of each Verification Testing period.

Additionally, calibrated mono-sized polymer microspheres in sizes of 2, 10, and 15 $\mu$m should be used for the verification. The procedure is as follows:

- Analyze the particle concentration in the dilution water;

- Add an aliquot of the microsphere suspension to the dilution water to provide a final particle concentration of approximately 50,000 particles per 25 mL (2,000 particles per mL), and then gently swirl the suspension;
- Promptly analyze a suspension of each particle size separately to determine that the peak of particle concentration coincides with the diameter of particles added to the dilution water;
- Prepare a cocktail containing all three microsphere solutions to obtain a final particle concentration of approximately 1,000 particles per mL of each particle size; and
- Promptly analyze this cocktail to determine that the particle counter output contains peaks for all of the particle sizes.

*Maintenance.* The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the pilot study, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

*Particle-Free Water System.* "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-$\mu$m cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

*Glassware Preparation.* All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by hand washing using hot water and laboratory glassware detergent solution followed by a triple PFW rinse. Sample beakers will then be stored inverted.

Dedicated beakers will be used at all times for unfiltered water, diluted unfiltered water, prefiltered water (if prefiltration is used), filtered water, and PFW. When several samples are collected from various pilot plant sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection.

Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

*Sample Collection.* Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to

sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

*Dilution.* The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water.

When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$\text{Sample Particle Concentration} = \{MP - (1-X)(PF)\}/X \qquad (6\text{-}1)$$

where MP is the measured particle concentration (particles per mL) in the diluted sample, PF is the measured particle concentration (particles per mL) in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04.

*Particle Counting Sample Analysis.* To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the

appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

*In-line Particle Counters*

~~Particle counting of the permeate may be performed on-site with either the bench-top or in-line particle counter.~~ Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 $\mu$m and have a coincidence error of less than a ten percent. <u>The rate of flow through the sensor must be within the operating range specified by the manufacturer and must be measured and documented.</u>

The sensors of the in-line units must be provided with an updated manufacturer calibration. The calibration will be verified by measurement of the individual and cocktail solutions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

**Chemical and Biological Samples Shipped Off-Site for Analyses**

<u>Organic Parameter: Total Organic Carbon</u>

Samples for analysis of TOC shall be collected in glass bottles supplied by the NSF-qualified laboratory and shipped at 4°C to the analytical laboratory ~~within 8 hours of sampling~~. These samples shall be preserved<u>, held, and shipped</u> in accordance with Standard Method 5010B. <u>Storage time before analysis shall be minimized, according to *Standard Methods*.</u>

<u>Microbial Parameters: Protozoa and Algae</u>

Microbiological samples shall be refrigerated at approximately ~~2 to 8~~ <u>4</u>°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately ~~2 to 8~~ <u>4</u>°C during shipment. Samples shall be processed for analysis by an NSF-qualified Analytical Laboratory within~~24 hours of collection~~ <u>the time</u>

specified for the relevant analytical method. The laboratory shall keep the samples at approximately ~~2 to 8~~ 4°C until initiation of analysis.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately ~~2 to 8~~ 4°C, and held at that temperature range until counted.

Microspheres

The membrane filters used for obtaining microsphere samples shall be refrigerated at at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment and in the analytical laboratory, until they are analyzed. This is done to minimize microbiological growth on the membranes.

Recovery of microspheres from suspensions held in glassware shall be evaluated by preparing a suspension of microspheres in which the number of microspheres used to make the suspension is estimated, based on either the weight of dry microspheres or the volume of microspheres in liquid suspension as provided by the supplier. After the suspension is prepared and mixed until it is homogeneous, five aliquots shall be taken and counted in the hemacytometer. After the microsphere density (concentration) has been calculated, aliquots of the suspension shall be diluted and filtered through polycarbonate membrane filters having 1 $\mu$m pore size. The elution and concentration steps described in Task 4 shall be followed, and the microspheres shall be counted in a hemacytometer. This shall be done five times, so that statistics can be developed on the recovery of microspheres in the sampling procedure.

As a check on possible interference from fluorescing organisms in the feed water, during each Verification Testing run in which fluorescent microspheres are used, a sample of feed water with no seeded microspheres shall be filtered through a polycarbonate membrane, and the particulate matter on the membrane shall be concentrated using the procedures for microsphere analysis, and the concentrate shall be examined in a hemacytometer by microscope, with UV illumination. If no objects of the size and shape of the microspheres are seen to fluoresce, displaying the same color as the microspheres, then fluorescent objects of the proper color seen in samples with seeded microspheres can be considered to be microspheres.

Microspheres may adhere to surfaces of tanks, vessels, and glassware. All glassware, holding tanks, and membrane filter manifolds must be cleaned between seeding events or sampling events.

Inorganic Samples

Inorganic chemical samples, including, alkalinity, hardness, iron, and manganese, shall be collected, ~~and~~ preserved and held in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples should be refrigerated at approximately ~~2 to 8~~ 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately ~~2 to 8~~ 4°C. ~~Samples shall be processed for analysis by an NSF-Qualified Laboratory within 24 hours of collection~~. The laboratory shall keep the samples at approximately ~~2 to 8~~ 4°C until initiation of analysis.

| Table 1. Generic Schedule for Verification Testing | | |
|---|---|---|
| Season | Initial Operations, Estimated Time | Verification Testing, Minimum Required Time |
| Season #1* | 1 - 6 weeks | 30 days |
| Season #2 | 1 - 3 weeks | 30 days |
| Season #3 | 1 - 3 weeks | 30 days |
| Season #4 | 1 - 3 weeks | 30 days |
| * Start at season of Manufacturer's choice, and progress through four consecutive seasons. | | |

Table 2. Water Quality Sampling and Measurement Schedule

| Sample or Measure For: | Minimum Frequency |
|---|---|
| Temperature | Daily |
| pH | Daily |
| Total alkalinity | Weekly |
| Hardness | Weekly |
| Total organic carbon | Weekly |
| Turbidity | Daily at bench to check continuous turbidimeters |
| Continuous turbidity monitoring | Use data at 1/4, 1/2, or 1 hour for calculations of long-term performance. Also note maximum turbidity observed each day. |
| Iron | Once each testing period or weekly if present in concentration of 0.3 mg/L or greater |
| Manganese | Once each testing period or weekly if present in concentration of 0.05 mg/L or greater |
| Total coliform bacteria | Twice per week |
| Algae, number and species | Weekly if no prefiltration used; twice per week if prefiltration used; 3 times per week if pressure across bag filter or cartridge filter increases by more than 5 percent of total allowable pressure increase in one day's time. |
| $UV_{254}$ absorbance | Weekly when sample for TOC taken |
| True color | Weekly when sample for TOC taken |

For schedule for microspheres, particle counting, and ~~*Giardia* or~~ *Cryptosporidium*, see Task 4.

Table 3. Analytical Methods

| Parameter | Facility | *Standard Methods* number or Other Method Reference |
|---|---|---|
| Temperature | On-Site | 2550 B |
| pH | On-Site | $4500\text{-}H^+$ |
| Total alkalinity | Lab | 2320 B |
| Total Hardness | Lab | 2340 C |
| Total organic carbon | Lab | 5310 C |
| Turbidity | On-Site | 2130 B |
| Particle counts (electronic) | On-Site | Manufacturer |
| Iron | Lab | 3113 B |
| Manganese | Lab | 3113 B |
| Algae, number and species | Lab | 10200 F |
| True color | On-Site | Hach Company adaptation of *Standard Methods* #2120 |
| $UV_{254}$ absorbance | Lab | *Standard Methods* |
| Total coliform | Lab | 9221 or 9222 |
| ~~*Giardia* and~~ *Cryptosporidium* | Lab | Use the method most recently approved by US EPA (NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods) |
| Microsphere counts | Lab | Li *et al.*, 1995 |

Table 4. Cartridge Filtration and Bag Filtration Equipment Operating Data

| Operating Data | Action |
|---|---|
| Feedwater Flow and Filter Flow | Check and record twice per day, adjust when >10% above or below goal. Record both before and after adjustment. |
| Filter Head Loss (filter inlet pressure and filter outlet pressure) | Record initial clean bed total head loss at start of filter run and record total head loss two times per day. Also record this separately for the prefilter if a prefilter is used. |
| Filtered Water Production | Record gallons or cubic meters of water produced per filter bag or filter cartridge for each filter run, and total water produced by the filtration equipment each day it is operated. |
| Bag or Cartridge Replacement | Record date and time for replacement, and total gallons or cubic meters of water treated before replacement, and the reason for replacement, such as terminal head loss or excessive filtered water turbidity. |
| Electric Power | Record meter reading once per day. |
| Hours operated per day | Record in log book at end of day or at beginning of first shift on the following work day. (Around-the-clock operation is recommended). |
| ~~All parameters will be checked only during times when the pilot plant is staffed.~~ | |

**REFERENCES**

Abbaszadegan, M., Hansan, M.N., Gerba, C.P., Roessler, P.F., Wilson, B.R., Kuennen, R.,and Van Dellen, E. 1997. "The Disinfection Efficacy of a Point-of-Use Water Treatment System Against Bacterial, Viral and Protozoan Waterborne Pathogens," *Water Research*, 31:3:574-582.

Alaska Department of Environmental Conservation, Drinking Water Program. 1994. "Approval of Alternative Filtration Systems in Alaska," October 14, 1994.

APHA, AWWA, and WEF. 1992. *Standard Methods for the Examination of Water and Wastewater*, 18th ed., Washington, D.C.

Hach Company. 1992. *Hach Water Analysis Handbook*, 2nd Ed., Loveland, Colorado.

~~Li, S.Y., Goodrich, J.A., Owens, J.H., Willeke, G.E., Schaefer, F.W. III, and Clark, R.M. 1995. "Searching for Reliable Surrogates in determination of *Cryptosporidium* Removal Rates for Filtration-Based Drinking Water Treatment Systems," In: *1995 Annual Conference Proceedings; Water Research*, AWWA, Denver, Colorado, 1087-1092.~~

Li, S.Y., Goodrich, J.A., Owens, J.H., Willeke, G.E., Schaefer, F.W. III, and Clark, R.M. 1997. "Reliability of Non-Hazardous Surrogates for Determining *Cryptosporidium* Removal in Bag Filters," *Journal AWWA*, 89:5:90-99.

LIST OF TABLES

**NSF EQUIPMENT VERIFICATION TESTING PLAN**
**BAG FILTERS AND CARTRIDGE FILTERS**

TABLE OF CONTENTS